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AF TECHNICAL REPORT NO. 5826

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THE EFFECT OF DIAL DIAMETER ON OCULAR MOVEMENTS AND SPEED AND ACCURACY OF CHECK READING GROUPS OF SIMULATED ENGINE INSTRUMENTS

William J. White

UNITED STATES AIR FORCE
AIR MATERIEL COMMAND
Wright-Patterson Air Force Base, Dayton, Ohio

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ABSTRACT

To determine some of the psychological factors which influence check reading of instrument groups, experiments were conducted on the effect of dial diameter on eye movements and on speed and accuracy of reading. The task of the subject was to check read a presentation of sixteen simulated engine instruments with pointers aligned horizontally and to indicate alignment or misalignment by a hand-held toggle switch. Dials of three sizes, 1 inch, 1 3/4 inches, and 2 3/4 inches in diameter, were studied. Eye movements were recorded by means of the corneal reflection technique.

The three dial diameters were studied in relation to response time, errors, frequency, and duration of fixations. Although the differences among these measurements were not always statistically significant, nevertheless, the medium sized dial, 1 3/4 inches, was superior to the other sizes. A definite pattern of fixations was demonstrated, which has significance for location of the most critical instruments.

PUBLICATION APPROVAL

For the Commanding General:

Ernest A. Pinson, Major, USAF.
for A. P. GAGGE
Lt. Colonel, MSC (USAF)
Acting Chief, Aero Medical Laboratory
Engineering Division

FOREWORD

This report was prepared by the Psychology Branch of the Aero Medical Laboratory, Engineering Division, Air Materiel Command, under Expenditure Order No. 694-27, with Mr. William J. White as Project Engineer. The study was suggested and supervised by Dr. W. F. Grether. Lt. H. G. Wise, now in the office of the Air Surgeon, Headquarters, USAF, assisted in some of the initial work of this investigation.

I. INTRODUCTION

The pilot and flight engineer of today's airplane are confronted with a large variety of engine instruments that must be compressed into a relatively small area of the instrument panel. With the advent of high-speed aircraft it is necessary that dial size be held to a minimum to accommodate the small fuselage cross-section and yet provide all necessary instruments. The problem arises of creating an instrument panel efficient in terms of both space utilization and readability. The Instrument and Navigation Branch of the Equipment Laboratory, AMC, Wright-Patterson Air Force Base, proposed in a Memorandum Report (4) that the Psychology Branch of the Aero Medical Laboratory investigate the psychological factors which influence the speed and accuracy of check reading a panel of aircraft engine or similar instruments. The proposal originated from the activity of the Equipment Laboratory in developing improved engine instruments and instrument arrangements.

Warrick and Grether (8) have shown that a rectangular arrangement of instruments, together with horizontal pointer alignment, provides a significant advantage in speed and accuracy of check reading, and that horizontal alignment in the 9 o'clock position is most desirable. As conservation of space must be taken into consideration in planning an instrument panel, the present study was undertaken to determine the effect of dial size on check reading. A further purpose was to study the manner in which the eyes are used in check reading instrument groups, and how the eye movements are affected by dial size. It can be assumed that the optimum instrument grouping and arrangement would involve a minimum of eye movements, minimum fixation time, and conform to the natural eye movement pattern used in daily activities.

Although no specific work has been reported in the literature on eye movements as they apply to instrument design, considerable work has been done on eye movements in reading (7), in scanning of pictures (1), and in searching for targets on radar scopes (5). The most suitable technique for the study of eye movements appeared to be the photographic recording of corneal reflections, as was done in this investigation by means of the American Optical Company Ophthalmograph.

II. EXPERIMENT I

Purpose:

This experiment was designed to measure the speed and accuracy of check reading instrument groups as a function of dial diameter.

Apparatus, Subjects and Procedure:

In this experiment, dials of three sizes, 1 inch, 1 3/4 inches, and 2 3/4 inches in diameter were studied. There were three mock-up instrument panels, one for each dial size, containing sixteen instruments arranged in a four-by-four square pattern as shown in Figure 1. The panels were designed so that the pointers could be set by knobs in the rear. The dial size, arrangement, and the pointer alignment were made to resemble current equipment with such modifications as proposed by the Equipment Laboratory.

The test panels were presented, as shown in Figure 2, in a Link Trainer fuselage 28 inches from and directly in front of the subject's eyes but below the horizontal line of sight. The simulated instruments were under constant illumination from two shielded cockpit lights, with the white markings at a brightness of approximately 30 foot-lamberts. During the testing period the canopy of the Link Trainer was closed, eliminating cues from the experimenter and external visual disturbances.

The instrument panel was covered by a cloth roller shade which was opened by a lever located at the experimenter's station. The opening of this shade started two electric timers. One of these was stopped by the subject, who held on his lap a three-position toggle switch, when making the correct response. The other clock stopped if an incorrect response was made. Thus, response time was obtained in case of either a correct or incorrect response, and the experimenter was provided with an indication of which response had been made by the subject. This system gave an accurate measure of response time and errors.

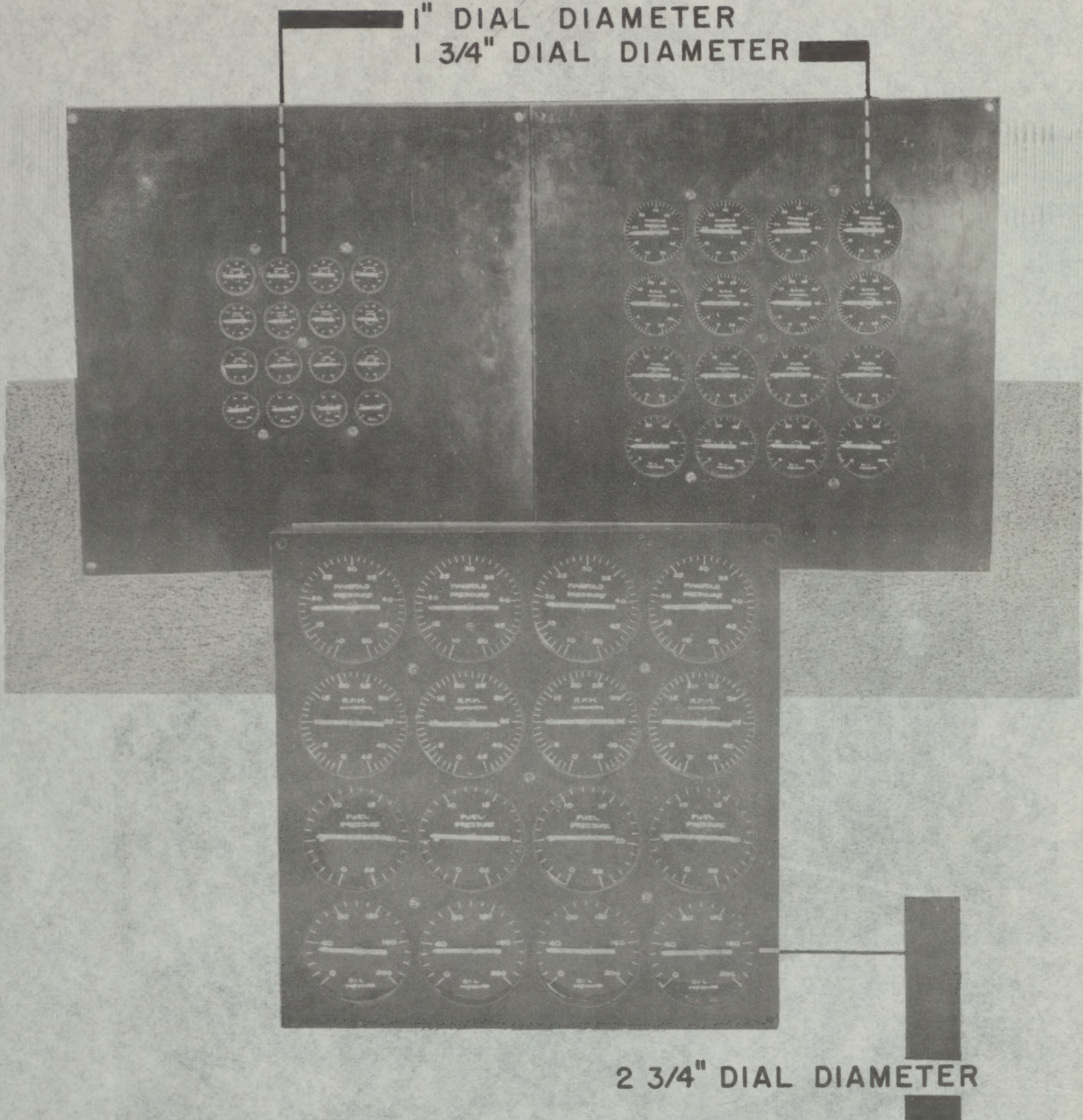
Twenty-four male subjects were used. All were personnel of the Aero Medical Laboratory, Wright-Patterson Air Force Base. Some of the subjects had participated in previous studies on check reading.

The subject's task upon the raising of the shade, was to check the panels as quickly and accurately as possible for any deviating pointers. The toggle switch, held on the subject's lap, was to be moved to the right if all pointers were aligned, to the left if any pointer was deviating. There was never more than one pointer deviating per trial, and this deviation was always 20, 40 or 60 degrees so that there would be no confusion between actual deviations and slight irregularities of alignment. Alignment was always in the horizontal plane, with pointers set in the 9 o'clock position. The order of presentation of the three panels was counterbalanced among the 24 subjects, and the order of trials randomized. Each subject was given 72 trials equally divided among the three dial sizes.

Among the 28 trials on each dial size there were ten with all pointers aligned, nine with one pointer deviating downward and nine with one pointer deviating upward. The positions of the deviating pointers were randomized among the 16 instruments.

Two scores were obtained: response time and errors. An error consisted of operating the toggle switch in the incorrect direction. Some of the errors may have resulted from confusion as to which way to move the switch rather than from failure to judge alignment or misalignment.

In a typical experimental session the subject was seated in a modified Link Trainer fuselage, instructed as to his task, and given three practice trials. After the practice period the canopy was lowered and the experiment begun. The test administrator lowered the shade, made the necessary adjustments to the simulated instruments from the rear of the panel, and gave a verbal "ready" signal to the subject before the trial. When the curtain was raised, the subject scanned the panel and responded by either right or left motion of the toggle switch. With the completion of the check the curtain was lowered, except when the response was in error. In this case the curtain remained up until the response was corrected.



Interchangeable Panels of Simulated Engine Instruments Used in Experiments I and II

FIGURE 1

Experimental Situation

USAF-TR-5826 FIGURE 2

Results:

The results of Experiment I are summarized in Table 1 which gives the mean response time and percent of total trials in error for the three sizes of dials. Also given in the table are the differences in response time and errors for the three sizes of dials and the significant ("t") values for these differences. In computing the response time a median was obtained using only those trials in which the response was correct. From such medians for all subjects the mean response times, given in Table 1, were computed. It will be noted that for the medium sized (1 3/4 inch) dial both response time and errors were lower than for the other two dial sizes. Only for the comparison of the 1 3/4 and 2 3/4 inch dials, however, were the differences in response time and errors significant at the 5 percent level of confidence.

TABLE 1

Mean response time and errors for check reading groups of 16 instruments varying in dial diameter (24 subjects each having 28 trials at each dial size)

Dial diameter in inches	Response time in seconds	Percent of trials in error
1	0.67	4.6
1 3/4	0.65	3.1
2 3/4	0.69	6.4

Significance of differences in response time

Dial diameter in inches		1 3/4"	2 3/4"
1	diff.	0.02	0.02
	"t"	1.36	1.12
1 3/4	diff.		0.04
	"t"		2.10*

Significance of differences in percent errors

Dial diameter in inches		1 3/4"	2 3/4"
1	diff.	1.5	1.8
	"t"	1.475	0.961
1 3/4	diff.		3.3
	"t"		2.50*

* Significant at 5 percent level of confidence. Other comparisons are not statistically significant.

III. EXPERIMENT II

Purpose:

The purpose of this experiment was to determine the frequency, duration, and pattern of eye movements made in check reading instrument groups varying in dial diameter.

Apparatus:

The stimulus materials, comprising three panels of simulated instruments, used in this experiment were identical to those used in Experiment I. However, certain modifications were made so that the panels could be displayed in conjunction with an American Optical Company Ophthalmograph (Fig. 3). A stand was constructed and secured to the Ophthalmograph so that the eye line of the seated subject was horizontal and intersected the center point of the panel. An opening in the stand permitted individual presentation of each panel 28 inches from the subject's eyes. This opening was covered by a quick acting shade. This shade was controlled from behind a screen that flanked the panel, thus minimizing the possibility of the subject being distracted by the experimenter. The panel was under constant illumination from two shielded cockpit lights with white areas at a brightness of approximately 30 foot-lamberts.

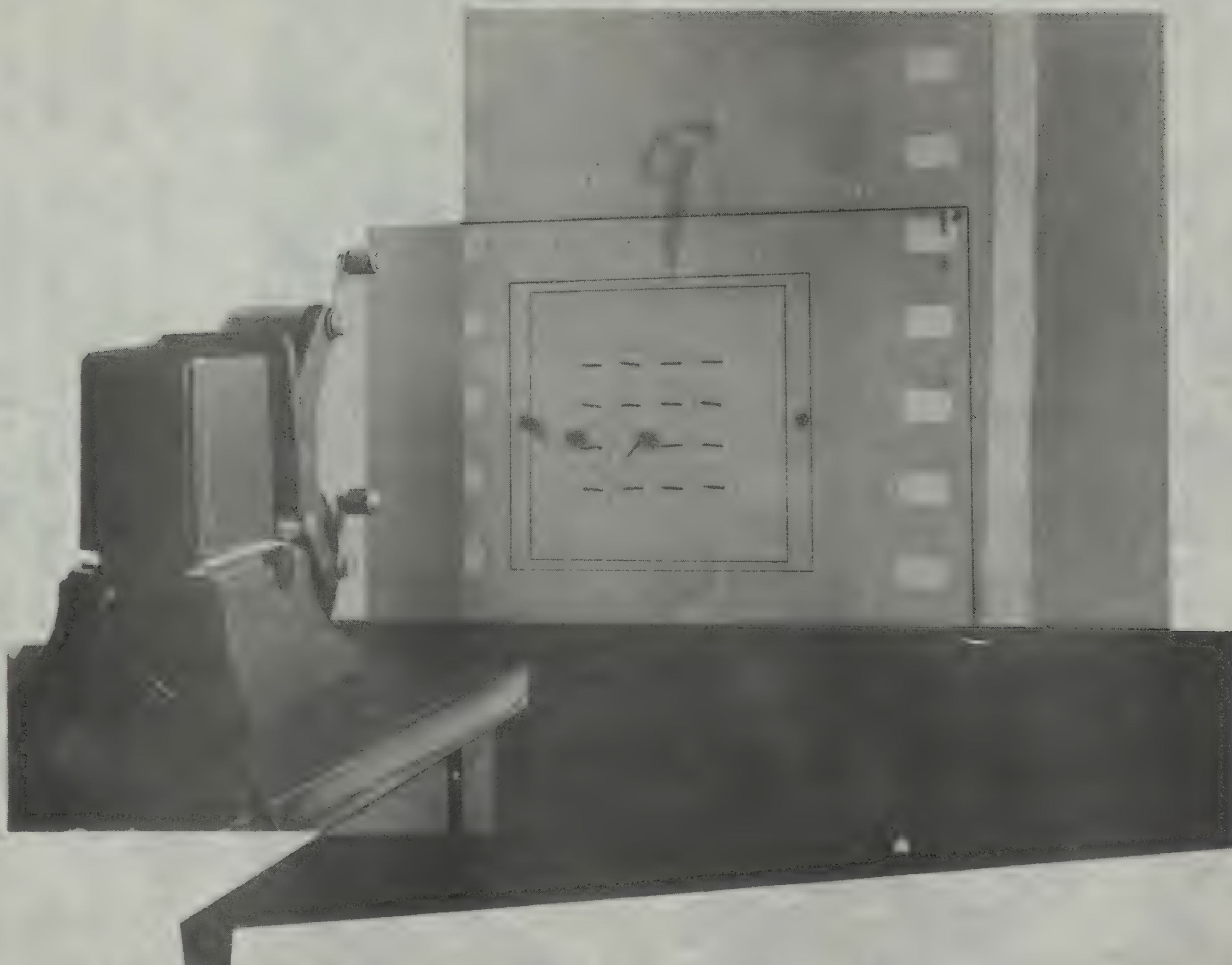
The Ophthalmograph, ordinarily used in studying eye movements in reading, was modified to suit the purposes of this experiment. This instrument records eye movements photographically by means of a bright light reflected from the cornea, a method developed by Dodge (2). As the eye moves, the cornea changes its angle to the incident light, and consequently causes a change in the position of the reflected light on the photographic film. In normal use, for recording of eye movements during reading, the 35 mm film moves at a steady rate so as to produce a record of lateral shifts and duration of fixations. For the present experiment the camera was modified to permit brief exposures with the film stationary. The record then obtained indicated both lateral and horizontal shifts, but provided no record of the duration of each fixation. Moving film records were also obtained in this experiment to provide data on duration of fixation. The light used to produce the reflection from the cornea was re-mounted on top of the case holding the lens, so that the lower lid and lashes of the eye would not obstruct the light reaching the cornea.

Procedure and Subjects:

The instructions to the subject were essentially the same as in Experiment I, except that a preliminary and final fixation point was introduced. These points were in an area not covered by the shade on the right and left margin of a stand holding the test material, and were placed there to facilitate the orientation of the film in relation to the stimulus material when projected. The subject was instructed to fixate the preliminary point until the curtain ascended, then to check the panel, throw the switch, and fixate on the final point. Detailed instructions were presented to the subject by means of a wire recorder so as to minimize any change in emphasis on the words "accurately" and "rapidly". In this same manner the subject was given a brief explanation of the principle on which the camera operated.

EXPERIMENTAL SITUATION; A. OPTHALMOGRAPH; B. LIGHT TO PRODUCE THE REFLECTION FROM THE CORNEA; C. STIMULUS MATERIAL; D. LIGHTS FOR ILLUMINATING PANEL; E. TIMERS; F. TOGGLE SWITCH; G. PRELIMINARY FIXATION POINT; H. WIRE RECORDER

USAF-TR-5826 FIGURE 3



Projection Technique Used in Experiment II

FIGURE 4

Initially considerable difficulty was encountered in obtaining interpretable photographic records. It was discovered that the subjects were making anticipatory fixations prior to the raising of the curtain, which produced rather large inconsistencies of number and duration of fixations. This was overcome by modifying the instructions and asking the subject to inhibit all anticipatory shifts away from the preliminary fixation point.

Three subjects had their preliminary fixation point to the left of the stimulus material and two to the right of the material. Five trials were given each subject for practice and to accustom him to the unusual reading situation. Among the 4 trials on each dial size there were 20 of the stationary film type and 4 with the film in motion. The experiment was divided into three 20 minute periods so as not to unduly fatigue the subject. The interval between periods was approximately one week.

Since no abnormalities of convergence were found in any of the subjects used in the experiment it was decided to record only the movements of the right eye, which would reduce the time and labor required to analyze the records. The apparatus used in this experiment was located in a darkened room, the only lights being those directed on the stimulus material and a light source for producing the reflection from the cornea.

Analysis of eye movement records:

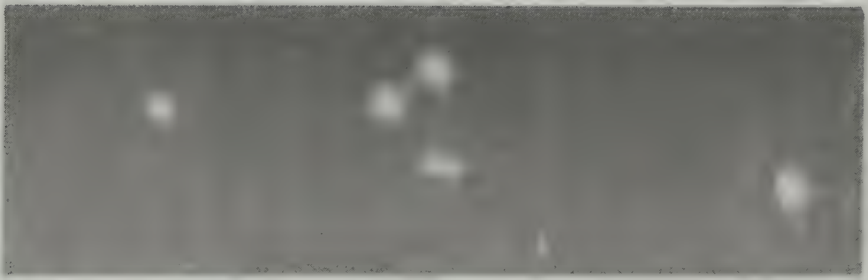
The film records obtained during the stationary film exposures were subjected to a frame-by-frame analysis to determine the number and pattern of fixations during each test trial. This analysis was accomplished by using a single frame projector to project on distorted reproductions of the actual panels which served as projection screens. Such distortion was necessary because the vertical shifts in fixation give smaller deviations in the corneal reflection than horizontal shifts of equal angular magnitude. The preliminary and final fixations as they appeared on the film were aligned with those on the reproductions. Thus, the intervening fixations fell approximately on the panel locations at which the subject had fixated, as shown in Figure 4.

The amount of distortion was determined by having each subject fixate the corners of the stimulus material, which was a square, and plotting from the projected film an average location of the fixation points. This determined the vertical and horizontal proportions. The resultant reproductions were rectangular rather than square.

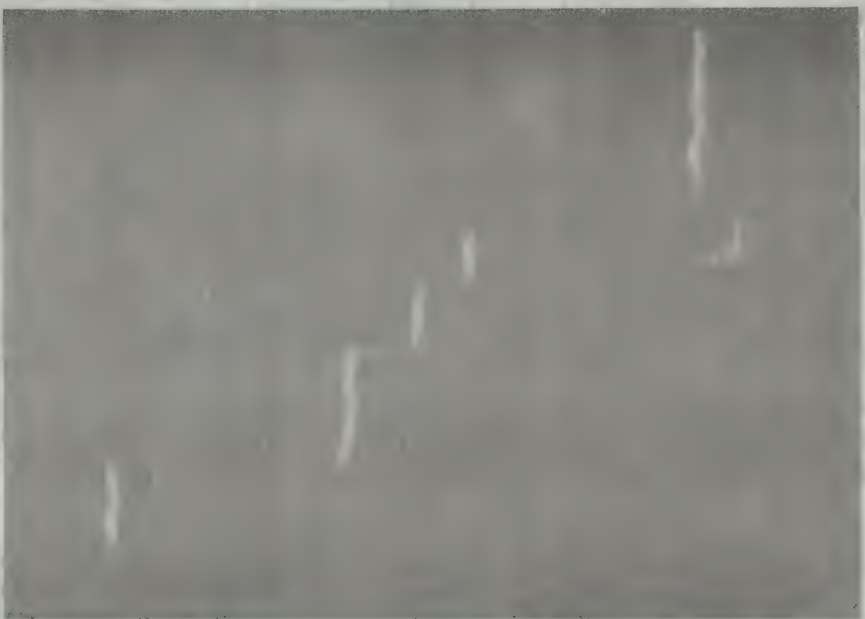
The duration of fixations was determined from the exposures taken with the film in motion. The resulting records were placed in a moviola projector, which had a scale attached to the viewing lens graduated in tenths of a second for the particular film speed. Thus, it was possible to read directly the duration of each fixation, which appeared as a line on the film. A typical record obtained with the film in motion is shown in Figure 5.

Results:

The results obtained from the analysis of the eye movement records in relation to dial diameter are shown in Table 2. The first row of the table gives the average number of fixations per trial in scanning the group of



AN UPWARD DEFLECTION OF THE EYE-LINE INDICATES AN EYE MOVEMENT IN THAT DIRECTION. THIS RECORD WAS OBTAINED DURING THE STATIONARY FILM EXPOSURE.



AN EXPOSURE TAKEN WITH THE FILM IN MOTION. A DEFLECTION TO THE RIGHT INDICATES A MOVEMENT IN THAT DIRECTION. THE HEAVY LINES ARE FIXATIONS WHOSE LENGTH PROVIDES A MEASURE OF DURATION. THE LIGHT HORIZONTAL LINES ARE SACCADIC MOVEMENTS.

Eye Movement Records Taken During the Check Reading of a Simulated Instrument Panel

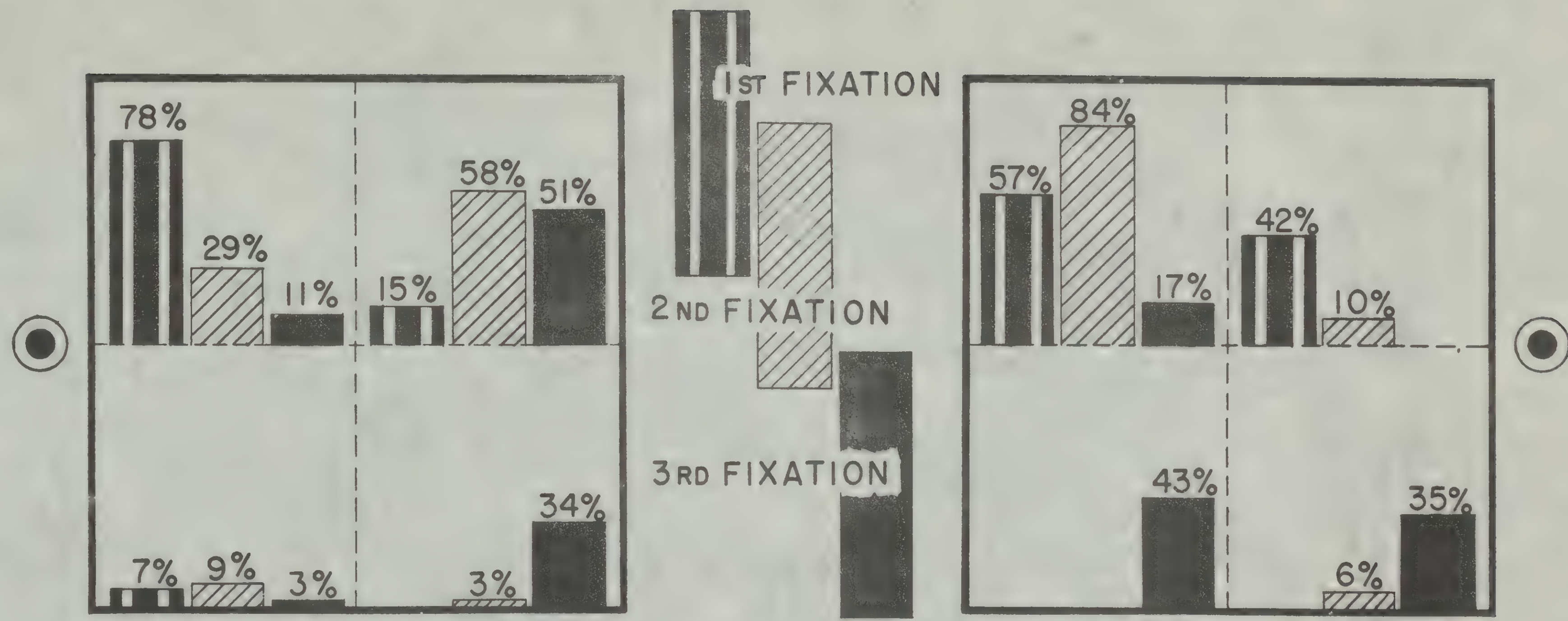
FIGURE 5

TABLE 2

Results of analysis of eye movements during check reading of instrument groups varying in dial diameter. (N = 6 subjects, 20 trials with stationary film and 4 trials with moving film for each subject at each dial size)

	Type of measurement	Dial Diameter		
		1 inch *	1 3/4 inch *	2 3/4 inch *
1.	Mean no. fixations per trial, all trials combined.	2.8	2.6	2.9
2.	Mean no. fixations per trial, moving film trials only.	2.8	2.6	2.6
3.	Mean sec. per fixation, moving film trials only.	0.29	0.26	0.26
4.	Total fixation time. (row 1 x row 3)	0.81	0.68	0.75
5.	Total scanning time, from preliminary to final fixation, moving film trials only.	0.82	0.72	0.75
6.	Response time, clock, all trials.	0.76	0.72	0.73
7.	Total number of errors.	8.0	6.0	17.0
8.	Percent deviating pointer trials on which deviating instrument was fixated, stationary film trials only.	72.0	71.0	81.0
9.	Duration of first fixation . (all dial sizes combined)		0.30	
10.	Duration of second fixation.		0.19	
11.	Duration of third fixation.		0.25	

* For none of the measurements are differences between dial sizes significant at the one percent level of confidence.



PRELIMINARY FIXATION TO THE LEFT OF THE TEST MATERIAL

PRELIMINARY FIXATION TO THE RIGHT OF THE TEST MATERIAL

DISTRIBUTION OF SUCCESSIVE FIXATIONS ON TEST MATERIAL

(N=6 SUBJECTS)

FIGURE 6

sixteen instruments, as determined from all trials (including both stationary and moving film exposures). The second row presents the same data from the moving film exposures only. In the third tow of the table is presented the average duration of fixations as determined from measurements of the length of fixation trials on the moving film exposures. The product of the number of fixations and the duration gives the total fixation time per trial given in the fourth line of the table. This can be compared with the total scanning time given in the next line, which was determined from the moving film exposures by measuring the distance between the end of the initial fixation and the beginning of the final fixation. This in turn can be compared with the mean response time, computed from the time clock recordings, presented in the sixth row of the table. In the seventh row is shown the percent of deviating pointer trials in which the deviating instrument was fixated, and in the last row is given the total number of errors. The last three rows give the average duration of the first, second, and third fixations for all trials and dial sizes combined.

A further analysis was made of the records to identify the general location of successive fixations. For this purpose the panel of sixteen instruments was divided into quadrants, and the frequency with which the first, second, and third fixations fell into each of the quadrants was tabulated. These results are summarized in Figure 6. It will be noted that the upper two quadrants were favored over the lower two, and the predominant tendency was to fixate first in the upper left quadrant, even when the initial or preliminary fixation was on the right side of the panel.

IV. DISCUSSION OF EXPERIMENTS I AND II

Although Experiment I does not indicate the clear superiority of any one dial size, the medium size, 1 3/4 inch, gave slightly superior speed and accuracy. The differences in response time and error scores among the three dial diameters suggest that within the range studied here there is a dial diameter which would give a significant advantage in speed and accuracy of check reading if sufficient test trials were given.

The results of Experiment II give a more detailed picture of the elements that determine the response time and error scores, as well as the relationship between dial diameter and check reading. The differences in the mean number and duration of fixations required to check the panel are so small as to be hardly significant. However, when the two are multiplied together to give the total fixation time, that is, the total time of exposure to the stimulus, a somewhat different picture results. When so measured the eye seems to be occupied with checking the panel the greater portion of the time in the 1 inch panel, in spite of the fact that the area is one-fifth that of the largest panel. The medium sized panel (1 3/4 inch) yielded the smallest total fixation time. This finding supports the superiority of this instrument diameter as demonstrated in Experiment I.

A comparison of these results with the study of Paterson and Tinker (6) is in order. Their study, confined to specific changes in eye movement patterns which take place in reading excessively small (6 point) type and unusually large size of type (14 point), led to the conclusion that striking

differences exist in favor of reading 10 point type as compared with 6 and 14 point sizes. The factor responsible for reducing the efficiency with which 14 point type is read is the increased amount of printing area that must be covered in reading a given amount of text. On the other hand, the decreased efficiency with which 6 point type is read is due to reduced visibility. The data in Table 2 are consistent with these results in that the medium dial diameter is read more efficiently and with greater accuracy than either of the two extremes.

The locations of the first three fixations on the stimulus material, presented in Figure 6, reveal that the location of the first fixation on the test material is relatively independent of the preliminary or starting fixation. One striking result is that the subjects tend to check read the upper portion of the panel first leaving the remaining portion until later in the scanning period. Analysis of the errors committed (Experiment I) shows that 22 percent more errors were made when the deviating pointer was in the lower half of the panel. Since the subjects tended to spend so little time in the lower portion of the panel it might be expected that the error ratio between halves would be greater, but Hall and Kries (3) have shown that the peripheral vision is more acute in the lower half of the visual field. It may be for this reason that the subjects tended to survey the upper portion of the field first, depending on the cues obtained in peripheral vision to detect deviations. This may be especially true in such a simple task as determining pointer alignment.

The establishment of a definite pattern of fixations is of value in laying out instrument groups. If the engine or similar instruments can be ranked in importance the results of this visual plotting suggest that the more important instruments should be placed in the upper rows.

The duration of successive fixations on the test material were found to be 0.30 sec. for the first, 0.19 and 0.25 for the second and third. The question arises as to why the first fixation required such a comparatively long time. One plausible answer is that the first fixation is one of orientation or exploration and during this period the dials on either side of the fixater receive some preliminary examination and consequently the second and third fixations are rapid and direct. Woodworth (9) reports similar results when computing the duration of fixation for each quarter of 151 lines of printed material. Thirty percent of the total time is spent in fixating the first quarter of the line while the other quarters receive on the average just about equal time.

This answer is supported to some extent by the findings obtained when an examination was made of the fixation points in relation to the deviating indicator. In the case of the 1 inch and 1 3/4 inch panels it was found that on 28% of the trials the deviating indicator was not fixated. For the large panel it was necessary to look directly at the deviating indicator before a confident response could be made as to the condition of alignment.

V. SUMMARY AND CONCLUSIONS

Groups of sixteen instruments with dial diameters of 1 inch, 1 3/4 inches, and 2 3/4 inches were studied to determine the effect of dial diameter on (a) speed and accuracy of check reading and (b) eye movements. The subjects were asked to check read a group of instruments as quickly and accurately as possible and respond by the operation of a toggle switch.

The following conclusions appear justified by the results of this investigation:

1. At a viewing distance of 28 inches instrument groups made up of 1 3/4 inch dials can apparently be check read with slightly greater speed and accuracy than similar groups of 1 inch or 2 3/4 inch dials.

2. The eye movements in check reading instrument groups appear to be slightly more efficient, in terms of number and duration of fixations, for a 1 3/4 inch dial than for larger or smaller dials.

3. In rapid check reading of an instrument group the upper instruments tend to be fixated first, and more frequently, than instruments lower on the panel.

4. In check reading an instrument group the first visual fixation in scanning the panel is of greater average duration than the immediately succeeding fixations.

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